Analysis of Five Weather and Climate Based Films: Fact or Fiction?

An Honors Thesis (HONR 499)

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Abstract

Filmography has developed extensively in history; from black and white films to color, silent films to sound effects, and even the visual special effects in the movies of today's culture. Enhancing factual information has remained a resilient component in much of the business as an act of augmenting the excitement of the audience and gathering large crowds at the box-office. Whether or not the plot in the movie could happen in reality is at times overlooked in order to create a more intriguing scenario for the characters to overcome. This is evident in many genres of filmography. I have chosen to focus on films that are based on various weather and climate related phenomenon. Several weather and climate based films have made their way to the big screen while others fall short as direct-to-television movies. Five movies were analyzed for their content and quality of truth; *Twister* (1996), *Whiteout* (2009), *The Day After Tomorrow* (2004), *500 mph Storm* (2013), and *The Perfect Storm* (2000). I have gathered evidence that will support or disprove some of the claims that are made in the movies in order to enlighten the audience of the possible weather and climate phenomenon that is represented in the films.

Acknowledgements

I would like to thank Dr. Jill Coleman for taking on the role of advisor to this thesis project. Her knowledge in the sciences of climatology and meteorology proved to be an impeccable guidance throughout this semester-long task.

I would like to thank my family for supporting my academic career and my endeavors here-on-after.

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Introduction

Filmography is well-known for its exaggerations on reality. In fact, just typing the words 'embellishment in filmography' into a search engine will yield several pages of articles about various movies that were based on a true story but were re-imagined into a story that leads the audience astray. Whether it is a movie based on a famous work of literature, a biography of a person's life, or scientific facts like the infamous global warming trend, writers and director's allow themselves to take artistic liberties with the story-line of their planned movie. At times the writers or directors can take those liberties too far and cause the audience to believe the embellishments.

Directors will sometimes admit that they have boosted the truth in order to make an attention grabbing movie. For example, in a New York Times article about *The Day After Tomorrow* (2004), Roland Emerich, the director, admits that the movie is based off of a book about climate change written by paranormal and extraterrestrial activists. He and his team sped up the progression of a decade to century long process of change in order to make the movie scarier for the audience. The article quotes Dr. Stefan Rahmstorf who studies oceanography and climatology as saying, "Given the rules and constraints of the genre, it is remarkable to what extent the filmmakers have tried to present some realistic background" (Revkin, 2004).

Embellishment of scientific phenomenon can jeopardize the safety of viewers. The audience believing the information in the movie rather than proven or heavily studied facts can be dangerous in many film genres; in terms of science-based genres there is particular danger with weather-related story-lines. When directors stretch the truth about weather or climate, people may believe that doomsday is just around the corner or that it is safe to strap yourself to a plumbing line prior to an F-5

tornado passing directly overhead. Unsafe emergency practices that have been observed in the movie could lead to injury or death when tornados, hurricanes, flash floods, blizzards, and other weather events occur. Inaccurate information that has been retained from a movie and not questioned by an audience member could lead to a fear of Mother Nature. It could also lead to overconfidence in knowledge of an event such as a tornado outbreak. This overconfidence may put people's lives in danger if a group of individuals chose to chase storms in a tornado outbreak without having the proper training and knowledge.

With this project I hope to inform readers about the reliability of important factors in several weather and climate-based films. These films range from production in the 1990s to the most recent one in 2013. The focus varies from catastrophic climate change to mesoscale tornadic events and even polar climate conditions. With the analysis of the facts that are presented in these films, readers will be better prepared to identify exaggeration in future films from this genre as well as be interested to learn more about weather and the climate. The added scientific knowledge may then allay any preconceived fears about severe weather and climate conditions stemming from movie portrayals.

Climatologically Based Films

Climate is a term used to refer to the state of the atmosphere for a region over a given amount of time. A region's climate is derived from the averages of several months, years, or decades of weather records like temperature and precipitation. Some classification methods even use vegetation to identify a regional climate. Climatology is the study of these weather averages, how they may be changing and their impacts on various aspects of the earth's climate.

Polar Regions experience a unique climate as compared to the tropics or midlatitude areas. The film *Whiteout* (2009) highlights a few important features of cold climates along with several safety measures that are necessary when living in a region that experiences extremely cold temperatures. Cold weather also plays a role in the movie *The Day After Tomorrow* (2004) although the main theme in the film is climate change. Climate change is a term that invokes fear in some individuals and skepticism in others. It is highly questionable that a shift in the climate would occur as quickly or in the manner that it does in the movie. However, this film highlights the fact that if climate change is not accepted and drastic measures are not taken, then a shift in the climate could be catastrophic to the world that we know today.

Cold Weather Climates – *Whiteout*

Whiteout (2009) stars Kate Beckinsale as Carrie, a U.S. Marshal stationed in Antarctica who becomes entangled in a mysterious death of a Russian scientist during winter evacuation of the research base. Carrie is torn between ruling the death as homicide which would result in a federal investigation leaving her on the base all winter or to rule the death as an accidental fall. As a major storm approaches and blizzard or whiteout conditions descend on the base, the evacuation process must be sped up leaving Carrie with little time to solve the mystery. She pulls together a small team of a pilot and an investigator from the UK to solve the case and stop the murderer who is still running rampant around Antarctica. *Whiteout* highlights extreme Antarctic conditions while touching on some lesser known facts about the weather at and around the South Pole. In order to catch some of these facts, the audience must pay attention not only to the commentary of the characters, but also the labels that are presented on the screen as Carrie travels to different locations that are registering different weather conditions at the time. In general, the information in the movie is factually sound with only a few aspects straying from reality.

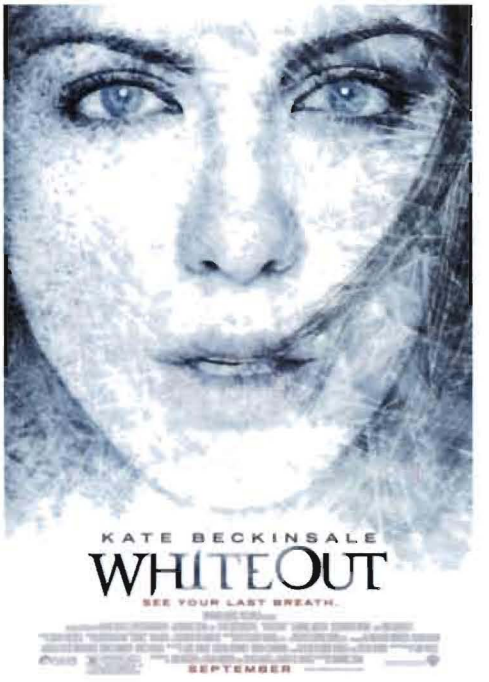

Figure 1: *Whiteout* movie poster (International (International Movie Database, 2015)

Instrumentation and Gear

Antarctica is a vast frozen desert with a short history of weather records from surface stations. These surface stations house instruments such as thermometers to measure temperature, hygrometers to measure humidity, anemometers to measure wind speed and direction, and a variety of other tools. With the implementation of satellites, remote sensing data has allowed for monitoring of the entire

continent. Satellite imagery allows for disturbances in the atmosphere to be viewed and tracked from above. This means that scientists can predict whether a low pressure system will impact the continent, how intense it may be, and what direction it has traveled and will be traveling.

Across Antarctica are several bases that have been established by many countries of the world. No single country has ownership of the continent. In 1959 a treaty was signed by the twelve active countries in Antarctica in order to maintain peaceful operation on the continent and to prevent any country from taking the claim of territory from another country. The number of countries recognizing the Antarctic Treaty is now at 52. Seventeen of those countries have been acknowledged as performing scientific research and activities on the continent (Secretariat of the Antarctic Treaty, 2011).

The United States operates three main bases on the continent along with a number of summer camps. *Whiteout* begins at one of these bases known as the Amundsen-Scott Base. At this base, research is conducted in an assortment of scientific areas including glaciology, geophysics, meteorology, atmosphere physics, astronomy, and biomedical science (NASA Quest, 2011). Carrie also visits the Vostok station which is under Russian control. The Vostok Station observes meteorological activity, snow line measurements, ozone measurements, geomagnetic observations, drilling into the ice sheet, and the influence of environmental factors on the health of certain participants (Federal Program; Antarctic Research and Investigation).

As the base workers move from one building to another, they attach themselves to a cable system that links all of the buildings on the base together in a sort of maze. These cables are known as blizzard lines and allow a person to find their way across the land especially in times of low visibility. This concept was first described in British literature of an expedition that took place from 1907-1909 (Hince, 2000). This way of traversing from building to building becomes even more essential as the wind speeds pick up and visibility drops. The reason for this system is to keep team members from getting lost and

disoriented in the whiteout conditions. Under normal circumstances, this form of travel could be seen as essential for the safety of the team members on the base. Under the circumstance of being chased by a murderer, the blizzard lines turn into an obstacle rather than a safety provision. Carrie gets into trouble as she is attempting to detach her carabineer at the end of one cable and then reattach her carabineer to the next cable while the killer is chasing her around outside.

Doc is a character in the movie that plays an important role in the plot. In the beginning he appears to be the sweet old man who has spent years as the doctor on the Amundsen-Scott Base. He is training a set of newcomers on how to survive the cold temperatures. Within three minutes of removing their jackets and having no coverings on their faces or hangs, their motor skills are impaired and their functional brain speed is significantly slower. If the temperature of a human drops below 96.8° F the performance of physical activity begins to be adversely affect and for body temperatures below 82.4° F there will be significant health effects to the cardiovascular system, the respiratory system, and behavioral aspects of an individual (Hassi, Rykoenen, Kotaniemi, & Rintamaeki, 2005). The risk of health and brain activity being affected by the cold temperatures of Antarctica makes it imperative that the right gear is used and worn by the base members. Insulated coats, gloves, and pants along with face coverings and goggles are a necessity especially if the wind is blowing heavily enough to pick up snow.

Wind chill plays an important role not only in the perception of how cold the air feels outside but also with the health effects exhibited on the body. The time that it takes for frostbite to occur on the human body increases as temperature decreases as well as wind speed increases. Figure 2 depicts the amount of time it takes for frostbite to be exhibited on the body as well as the change in the time it takes for frostbite to occur in relation to temperature and wind speed. At -10° F in calm winds, it would take approximately 30 minutes for frostbite to occur on the human body. As winds increase in speed, the time drops down to 10 minutes and then even to five minutes. Based off of the temperatures and

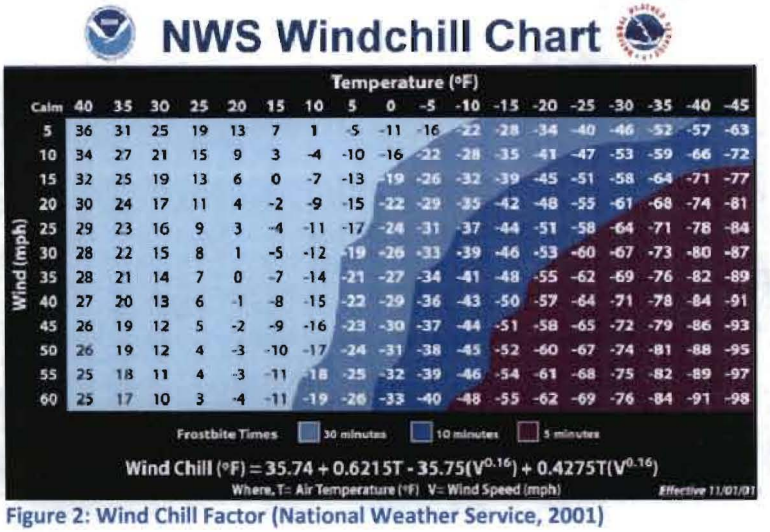

Figure 2: Wind Chill Factor (National Weather Service, 2001)

wind speeds that are portrayed in the movie, for example -85° F at the Vostok Station, frostbite would have occurred within five minutes.

During one of the action scenes that take place at the Russian base, Carrie loses her glove while traversing from one building to another as whiteout conditions begin to affect the different bases. She gets to a door where she must use both hands to spin the wheel locking mechanism and the hand without the glove freezes to the metal. When she pulls her hand off, a large amount of skin remains on the wheel and her hand is left frozen and bleeding. She eventually has to have two fingers amputated due to the frostbite that damaged her nerves past repair. In fact, she cannot feel anything on those two fingers when they are being examined by Doc. Heat transfer to cold metal occurs extremely quickly especially if that metal is in the Arctic. The station that Carrie was at had a temperature of -85° F. When temperatures are below freezing, the moisture on bare skin can freeze to metal upon contact. The freezing point of that moisture is 32° F. Just below freezing, a layer or two of skin might pull off when skin is frozen to metal but at the temperatures that are being recorded at the base in Antarctica, it is not unreasonable that a large portion of skin was left behind and her fingers were instantly frostbitten (Curtis, 2010).

Norms and Records for the South Pole

The temperatures presented on the screen for the different bases range from -58°F to -85°F. Average temperatures for the Amundsen-Scott Base in Antarctica range from about -18°F to -76°F (National Science Foundation). The Vostok Station can have an average range of -27°F to below -94°F (Federal Program; Antarctic Research and Investigation). Thus, the temperatures being reported

throughout the film are within a reasonable range. Antarctica is a place of extremes with the coldest global temperature recorded, based on satellite observations, as -135.4°F on August 10, 2010; (Woo, 2013) thus breaking the previous world record of -128.2°F held by the Vostok Station on July 21st, 1983 (Discovering Antarctica).

During one scene of the movie, the two men who are helping Carrie solve the case are talking about their days spent in the Middle East. One of them says that they traded one desert for another. Most people associate deserts with dry and hot environments like the Sahara or the Mojave deserts. It is at times overlooked that Polar Regions can be considered deserts as well. The Köppen Climatic Classification Scheme gives certain criteria for a location to meet based on the time of the year that most of the precipitation falls and an equation that includes temperature. For example, a true desert climate would exist if more than 70% of the annual precipitation occurs in the winter half of the year and the total precipitation averages are less than the total temperature averages in degrees C for temperature and cm for precipitation (Rohli & Vega, 2015). Figure three is a climograph from the Amundsen-Scott Base in Antarctica. Depicted in the graph are the mean temperature per month and the mean precipitation per month. Annually, Antarctica receives about 7.2 inches of precipitation.

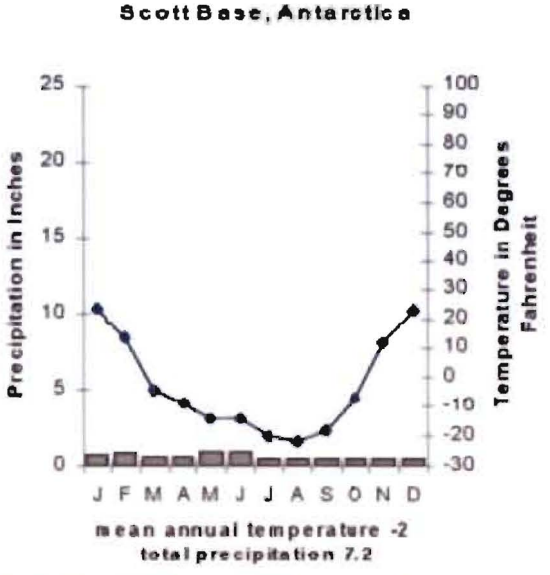

Figure 3: Climograph for Amundsen-Scott Base in Antarctica. The line represents the average temperatures for each month of the year and the bars represent the average precipitation. (Hill, 2014)

Antarctica gets its desert-like climate for several reasons. Antarctica's highest elevation is over a mile and a half above sea level. This is because of the ice that has built up above the actual land mass. The high elevation and the latitudinal location of Antarctica lead to a low sun angle in the sky during the

time when they do receive sunlight. This solar insolation is spread across the vast area of the continent and does not provide a lot of heat to be absorbed. Ice and snow have high albedo values therefore most of the solar insolation that would reach Antarctica will be reflected back into the atmosphere preventing it from heating the surface. Positioned above the center of the continent is a high pressure system that leads to clear and dry weather conditions. Winds move from areas of high pressure to areas of low pressure, thus with the high pressure sitting over Antarctica, a wind pattern forms when that air moves down the slopes of the continent and towards the coast. The process of wind traveling down the slope is known as katabatic wind. The winds that go through the katabatic process near the poles are known as the polar easterlies (Discovering Antarctica).

Circulation and Whiteout Development

The investigation into the homicide of the first scientist and the search for the suspect is on a tight schedule due to an advancing storm system. The station was already being evacuated for the winter season, which is April-September in the Southern Hemisphere, when the body is found. The evacuation is sped up due to the incoming storm that is supposedly bringing whiteout conditions to the continent. Storms in the Polar Regions are different from those that form in the midlatitudes and the tropical regions. In the Polar Regions, the cyclones are known as Polar Lows and they form over high latitude oceans where there is enhanced moist convection. Along with the moist convection, they occur where there are large temperature contrasts with either the polar front or warm water that is adjacent to an ice sheet. They can sometimes resemble a tropical cyclone (figure 4) in terms of having a central

Figure 4: The image on the left is of a polar vortex near Antarctica and South America. The image on the right is a tropical hurricane just east of the Florida coast.

eye with surface winds of about 30 m/s, yet are smaller in size from midlatitude cyclones. Polar lows have been observed to form rapidly; in as little time as one day, the polar low can reach its full mature structure (Montgomery & Farrell, 1992).

When Doc is training the new base members, he talks about a weather condition called a whiteout. He says that it is when "an unholy set of weather conditions converge" and wind speeds reach over 100 mph kicking up snow and limiting visibility to six inches in front of your face- if you're lucky. The Australian Antarctic Division (accessed 2015) describes a whiteout as "an optical phenomenon in which uniform light conditions effectively make it impossible to distinguish shadows, landmarks or the horizon." The website also describes blizzard conditions as being sustained gale force winds for more than an hour. Winds reach gale force when they are about 39 to 46 mph (Storm Prediction Center, 2015). Whiteout conditions are common across Antarctica but they are mainly due to blowing ice and not from fresh accumulation of snow (Rohli & Vega, 2015).

Conclusion

Whiteout hit upon some accurate facts and happenings in the Arctic climate. While Antarctica remains to be a continent with little historical data and much of it has yet to be explored, what is known about Antarctica was portrayed well in this movie. In most cases, the writers and directors stuck to the truth in terms of weather and climate. Carrie was able to pin down the murderer and the surprising character that was in charge of it all. She and the other two members of her team were forced to remain on the base through winter but they were able to form a bond that got them through the days where there was little sunlight and bitter cold.

Extreme Climate Change – *The Day After Tomorrow*

The Day After Tomorrow (2004) is a dramatic science fiction film starring Dennis Quaid, Jake Gyllenhaal, and Emmy Rossum. The movie revolves around an intense and abrupt climate shift that causes massive destruction and death throughout the world, specifically the northern hemisphere. Jack Hall (Quaid) is a paleoclimatologist who is working to get world leaders to understand what is changing with respect to the global climate and how fast these changes will occur. After certain events take place and some models are run, even he is shocked when the model outputs show the changes he described will take place in a matter of a few days versus his original thought of hundreds of years. His son (Gyllenhaal) is stuck in New York City due to a school program with some friends and will likely not survive the oncoming shifting and storms. This leads Jack to venture out in the storm to get to his son and the other survivors. This movie offers the audience an action packed thriller with a little bit of romance and of course a scientific plot and twist. The movie highlights some important issues concerning climate change and while it will likely not be as extreme as it is portrayed in the movie, climate change is something that must be understood in order to take it seriously and mitigate the concerns that have already arisen and are predicted to continue.

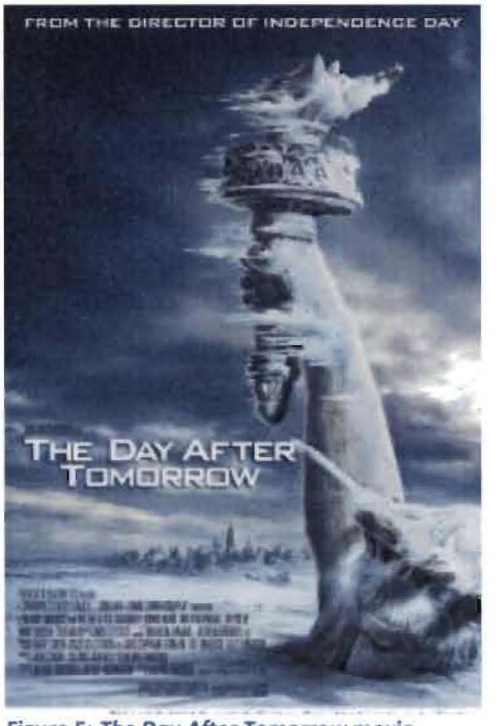

Figure 5: *The Day After Tomorrow* movie poster (International Movie Database, 2015)

Instrumentation

Instrumentation is needed to record the data that climatologists analyze to review what kind of shifts have taken or are currently taking place. In the beginning of the movie, Jack's small team of

scientists is drilling into the ice of Antarctica. What they are drilling for is not oil, but ice cores from deep within the ice shelf. These ice cores can be analyzed for chemical makeup such as CO_2, Nitrogen, Methane, and other gases that make up or used to make up the atmosphere. Studying the chemical composition of the atmosphere allows paleoclimatologists to create models of what the earth's atmosphere would have been like thousands of years ago. Understanding the past and mapping out the changes in the atmosphere can be a way of predicting the future and the possibilities of climate change. Different scenarios can be run to establish what would happen if humans continue living exactly as they are now, if they would eliminate carbon dioxide emissions to half of what it is today, or other various scenarios. Other forms of proxy data include tree rings, fossils, pollen, lake sediments, ocean cores, historical records, etc. (Rohli & Vega, 2015). The World Meteorological Organization (WMO) defines climate models as a computer-based model that allows climatologists to understand the behavior of the climate and to predict the future of the climate (accessed 2015). Climate models allow climatologists not only to piece together the past climate, but to predict the future climate as well.

In *The Day After Tomorrow*, the first notification that the climate is changing faster than expected is from buoys floating in the Atlantic that are being monitored by a research center in Scotland. When the first buoy alerts the team that there has been a 13 degree drop in ocean temperature, they attribute the significant change to rough seas in George's Bank which is located roughly 200 miles directly east of Staten Island. Buoys have been pivotal in the understanding and measuring of data over and in the ocean. Even today, the oceans are one of the last frontiers when it comes to gathering data. There is still much of the ocean that has no buoys to provide information on the temperature, humidity, ocean temperatures, etc. Figure 6 comes from the National Atmospheric and Oceanic Administrations National Data Buoy Center. As of April 24, 2015 there are 1251 stations that are deployed. However, not all of the stations transmit constant readings. At the time this image was taken, only 961 had transmitted readings within the last 8 hours. A large majority of the buoys that

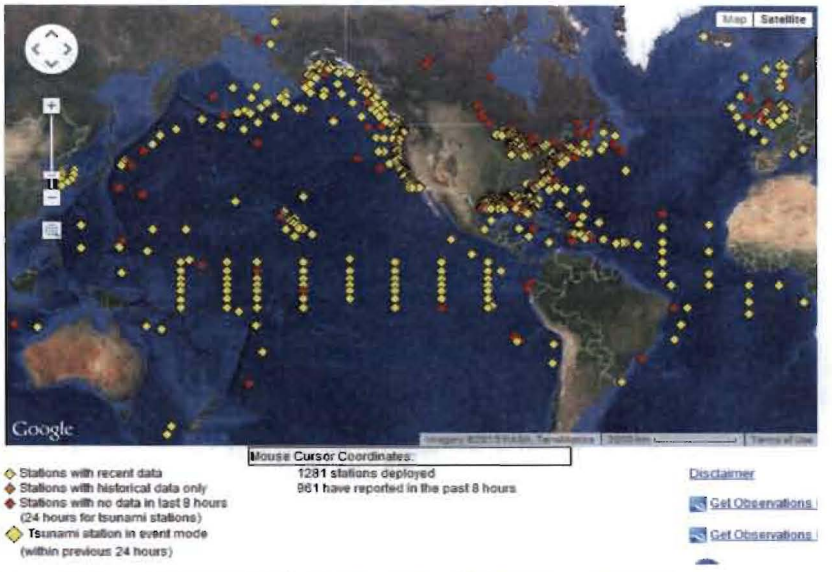

Figure 6: Buoys in operation (U.S. Department of Commerce, 2015)

are active by NOAA are located along the coastlines of the United States including the Great Lakes coasts. There is also a clear pattern that can be noted running horizontal around where the equator would be. It could be reasoned that this is due to the presence of the Intertropical Convergence Zone (ITCZ), the El Niño Southern Oscillation (ENSO) and the desire to track its shifting patterns. While it is true that other countries have their own measuring instruments and buoys, not all countries are willing to share their information and data.

Climate models are another influential technology that has continued to advance and augment the study of the climate. Models could be described as a mathematical representation of the earth, its atmosphere, and the various characteristics of the climate systems. Models can plot earth as a point or represent the atmosphere as a box with ingoing and outgoing radiation measurements. They can be simple or complex and use physics and chemistry to incorporate changes in the amount of greenhouse gases there are in the atmosphere and how those changes will affect a region or the entire global climate. Models can be used by paleoclimatologists to reconstruct the past; Jack's model that he describes at the conference in the beginning of the movie is one that is supposed to represent a past climate shift. Models can also provide valuable insight into the future like the one in the movie that tells them the entire northern hemisphere is going to freeze over and kill anybody north of the 30°N latitude line. To predict the future, model inputs and parameters can be tweaked to take into account possible

changes in the atmosphere. For example, models can give an output on what could happen if more CO_2 were added to the atmosphere or if it dissipates on a large scale within a specified number of years.

Terminology

The Day After Tomorrow revolves around earth's climate and the way it is changing. Therefore, it is necessary to have a cohesive definition for the two terms: climate and climate change. Climate refers to the averages of weather data like temperature and precipitation for a location over a given period of time. The climate of a region is the foundation to what the weather will be like for a particular part of the year. A regions climate is based off of data that has been collected with various weather instruments and/or reconstructed through the gathering and analysis of proxy data. Climate data is thus a collection of normal, extremes, and the frequencies that they occur. Global climate takes into account all of the various climates that occur throughout the world and how they affect the entire earth's circulations and patterns.

During the climate conference in New Delhi, Jack talks about a runaway warming that pushed the earth into an ice age. What he means by runaway warming is that the greenhouse gases attributed to a positive feedback in the atmosphere and warming. A positive feedback takes place when a change in one area of the atmosphere causes a direct change in another area of the atmosphere in a way that is to be expected. For example, in this scene of the movie he says that greenhouse gases are what lead to the warming of the planet. Greenhouse gases absorb outgoing longwave solar radiation and re-emit it back towards the earth which in turn leads to a rise in the temperature of the earth. Since an increase in greenhouse gas concentrations caused an increase in temperature, there is a positive feedback taking place.

Greenhouse gases today make up less than one percent of the earth's current atmosphere. A greenhouse gas is defined as a gas that 'traps' heat in the atmosphere through the absorption of

outgoing longwave radiation and re-emitting the radiation back towards earth. There are different types of greenhouse gases that are all released into the atmosphere through a variety of means. The most abundant greenhouse gas is water vapor. The water vapor in the atmosphere mainly comes from evaporation of ocean water and is removed from the atmosphere when it rains. Carbon dioxide is the second most abundant greenhouse gas. Carbon dioxide gets put into the atmosphere when humans and animals expel their breath, when cars burn fossil fuels, or when forest fires and volcanoes release smoke into the atmosphere. Methane, nitrous oxide, halocarbons, and ozone are all greenhouse gases as well.

Ice Age Criteria and What Causes Them

An ice age occurs when the earth experiences a long period of time with below normal temperatures. In addition to lower temperatures, glaciers begin to advance and ice sheets cover much of the earth. Ice ages can have periods where glaciers retreat and temperatures warm as well, however these periods occur on a much smaller time-scale and are called glacial/interglacial cycles.

Several factors must come together in order to create an ice age. Variations in solar insolation can either lead to a warming or cooling trend across the earth. The distribution of sunlight can be altered by variations in the earth's orbital tilt and eccentricity. These variations and the effects that they have on the earth's climate are known as *Milankovitch cycles* (Dessler, 2012). Decreasing the earth's tilt will reduce seasonality meaning that there will be a lesser distinction in the changing of temperatures and precipitation between the seasons. Increasing the eccentricity means that the earth's orbit around the sun will resemble more of an oval and less of a circle. When the earth is at its farthest point from the sun there will be less solar radiation to heat the surface and atmosphere.

Tectonic movement can also play a role in the development of an ice age. Earth's continents are always in motion. A shift in one of the tectonic plates that resulted in blocking warm oceanic circulation could lead to a vast change in temperatures for a region. This could allow for ice sheets and glaciers to

begin to advance and thus setting in motion a change in the climate possibly into another ice age (Eldredge & Biek, 2010).

Climate Norms

The Day After Tomorrow is a movie based on climate change. There are a myriad of different facts thrown out by characters of the movie that have some truth to them, alone with some facts that are stretched from the truth. To help differentiate between what is truth and what is bogus, it is important to understand the generic norms of the climate.

During his explanation of the warming leading to a cooling trend, Jack attributes the northern hemispheres climate to the North Atlantic Current, also known as the Gulf Stream. This is not the case. There are multiple characteristics of the atmosphere and earth itself that control the climate of a given area and can be used to explain why certain areas on earth have different climate conditions. Controls of climate include latitude, topography, proximity to water, pressure and wind belts, earth's rotation, oceanic circulation, and the sun.

It is true that the northern hemisphere is influenced by the Gulf Stream which brings warm waters northward and then across the Atlantic towards Europe. These warm waters are the source of warm moisture that fuels an unstable environment. This is why the climate on the east coast and the weather phenomenon vary greatly in terms of precipitation and temperature as compared to the west coast. On the west

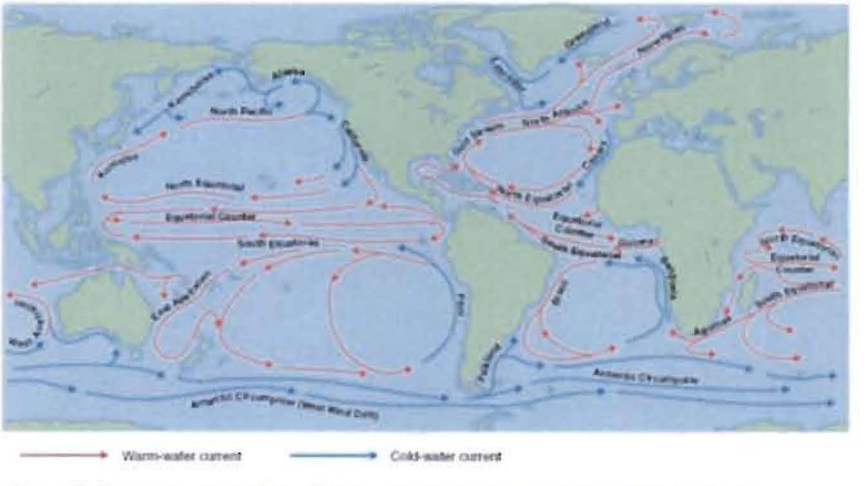

Figure 7: Ocean Currents (Satellite Applications for Geoscience Education)

coast, the current that affects North America is known as the California current and flows from the north to the south resulting in colder water being moved by the current. This leads to a more stable atmosphere above the ocean. The image above shows various ocean currents that exist on earth; the North Atlantic Drift is not the sole current in the northern hemisphere and thus would not be the only current that can take credit for the northern hemisphere climate.

After the people in the movie acknowledge that the climate is changing rapidly, NOAA holds a conference to gather opinions on why the change could be happening. One of the scientists blurts out "the only force strong enough to affect global weather is the sun." There is truth to the sun being able to affect global weather. A lack of sun spot activity in the late 17^{th} and early 18^{th} centuries led to one of the coldest periods of the Little Ice Age (roughly from 1500-1850). This event is known as the Maunder Minimum and led to a freezing of the Thames River in England (The Editors of Encyclopaedia Britannica, 2015). However, the sun is not the only force strong enough to affect the weather and climate on a global scale.

Volcanoes have the ability to affect global weather for years to even decades. If a volcano can spew ash and gases high enough into the stratosphere, the gases such as sulfur can stick around for years to come. These gases and the ash that is blown skyward impact the atmosphere by causing cooling because of the ash cloud blocking the solar radiation that would normally travel to the earth's surface to either be absorbed or reflected back. The gases can increase the effect of warming in the same ways that greenhouse gases affect the atmosphere already. In fact, the formation of the atmosphere that exists today was aided by the release of carbon dioxide when volcanoes erupted along with micro-organisms releasing carbon dioxide.

At the conference in New Delhi, one of the foreign representatives says that he is confused as to how global heating and cooling can take place at the same time. One way that this phenomenon can

occur is through the heating of ocean waters and in response the melting of ice sheets. As the ice sheets continue to melt, they are adding fresh water to salty ocean water thus decreasing the salinity of the oceans. This can affect the general circulation patterns. A shift may be experienced in the path of the ocean current, possibly from the loss of the normal ice sheets directing the currents one way or another which. If the warm currents that bring warm water to the eastern sides of the continent were to shut down or shift their path, the environment that is considered normal would also shift and this could cause a cooling trend in some areas whilst there is a warming trend in ocean temperatures.

Weather Phenomenon

In Los Angeles, the Coast Guard has closed the beaches as a low pressure system creates a cyclonic system that stretches across the California basin. Winds reach over 70 mph and there is baseball size hail that starts to fall on the beaches. The weather man in the movie gets a phone call telling him he needs to issue a tornado warning. As the scene plays out, there are twisters that start dropping everywhere over LA; one rips away the infamous Hollywood sign. Two of the twisters join together to form one large twister which continues to destroy buildings and throw people and cars across the city meanwhile people are standing around staring at the sky and trying to take as many pictures as possible rather than get to shelter. Just prior to this scene, a radio broadcaster can be heard saying that some of the local meteorologists are blaming the bizarre weather on sun spots and the weather man in LA can be quoted saying "it's Los Angeles, there is no weather here." That weather man is incorrect; weather occurs at all locations but the type of weather that occurs varies.

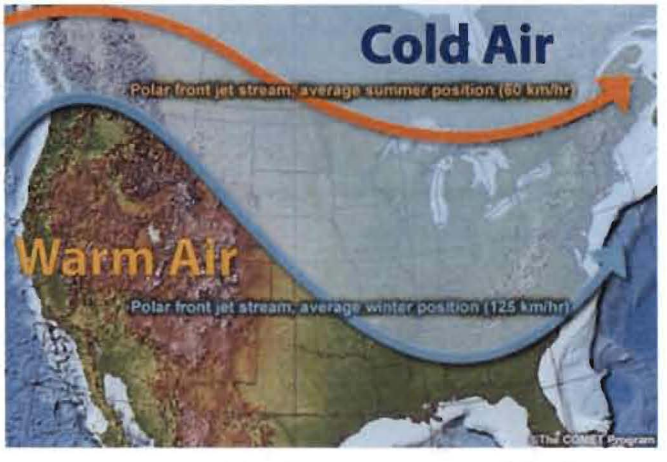

Figure 8: Average position of the polar jet stream (Blue Skies Meteorological Services, 2014)

The west coast of the United States is known for its sunny skies and lack of bad weather days at least on the southern portion of the coast. Along the states of Washington, Oregon, and even the northern coasts of California, there is more action in terms of precipitation and storms. One of the reasons that there is such a difference in the daily weather along the coast is the polar jet stream. The polar jet stream brings cold dry air from the northern regions of Canada. In the Midwest, this air can mix with the warm air from the Gulf of Mexico which leads to the formation of storms due to the convection that takes place. On the western side of the Rocky Mountains, the polar jet stream doesn't have as much affect; it usually dips down past the Rockies.

California experiences tornados but the magnitude and destructive strength is far from being as exaggerated as they are in *The Day After Tomorrow*. The strongest tornado recorded in California was an EF-3. The other tornados that affect California tend to stay within the EF-0 to EF-2 range. Between 1991 and 2010 there has been an average of 11 tornados per year. Tornados in California tend to occur in the winter and spring, peaking in March. This is the time of year when deep upper-level lows impact the state heavily (Livingston, 2012). A high pressure system forms in the Great Basin area and as the winds move from high pressure to low pressure, they can reach speeds up to 60 mph and affect LA heavily. These winds are known as the Santa Ana winds.

A different scene of the movie focuses on temperatures dropping to unbearable levels. In the UK, a helicopter has been dispatched to pick up the royal family and take them to safety. Somewhere over a mountain range the helicopters fuel lines freeze. Dr. Terry Rapson who is in charge of the Hedland Research Center says that the temperature would have to reach -150°F to cause fuel lines to freeze instantaneously. After the helicopter crashes, the survivors open the door and freeze upon contact with the cold air. Fuel lines generally do not freeze unless there is a presence of water inside of them in which case it is not supposed to be there and should be addressed by adding isopropyl alcohol

to the system. The reason why gasoline does not freeze is because it is made up of various molecules. The first of those molecules that would come close to freezing would be the alcohol molecules and those take colder temperatures than described in the film.

Conclusion

The Day After Tomorrow is a film that highly exaggerates climate change and its potential impacts. There is some truth to what is discussed in the movie, for example how global heating and cooling can coexist. However, the scale at which the events take place highlights the ability that Hollywood has to take liberties in their portrayal of weather and climate change events. Luckily for the characters of the movie, Jack was able to find his son and several other survivors and Mexico happily accepted US citizens as climate change refugees.

Meteorologically Based Films

Weather can be described as the state of the atmosphere at a specific moment in time. It can range from sunny and clear skies to pouring rain and lightning storms. There can be hot and humid days where a person is left wishing for a cool breeze to bitterly cold and snowy days to where a person would give anything to be on a beach somewhere. In either case, the most exciting weather phenomenon for movies and meteorologists tends to be severe and possibly destructive weather.

Tornados can leave a path of devastation for miles, overturning cars and ripping roofs off of houses. They can claim the lives of people who are not aware that a tornado is heading straight for them or those who don't have the safest shelter. *Twister* (1996) provides for an exciting look into the life of a storm chaser and how deadly tornados can be.

Some weather phenomena that occur can be difficult for one to wrap their mind around. The film *500 mph Storm* (2013) explores some weather spectacles with an interesting perspective and creative edge to at least make for an entertaining film. While *500 mph Storm* is highly fictionalized, *The Perfect Storm* (2000) is based off of a true story both in the loss of some brave fishermen and the combining of three separate weather events that claimed their lives.

Typical Mesoscale Weather – *Twister*

The movie *Twister* (1996) stars Helen Hunt and Bill Paxton as Bill and Jo Harding, two storm chasers from Oklahoma trying to find a way to better predict tornados and provide an early warning system for the dangerous storms. Bill had left the team in pursuit of a divorce from Jo and a career change to be a weather man on TV. He returns to join forces with the team one last time for a tornado chasing day that nearly takes his life on several occasions. If the love triangle between his future wife and Jo does not provide enough of a pull for the audience, then the action packed storm chasing provides even more entertainment. Throughout the course of the movie, the audience sees approximately seven tornados ranging in magnitude, size, and destructive capabilities and various near death experiences for the characters that defy logic.

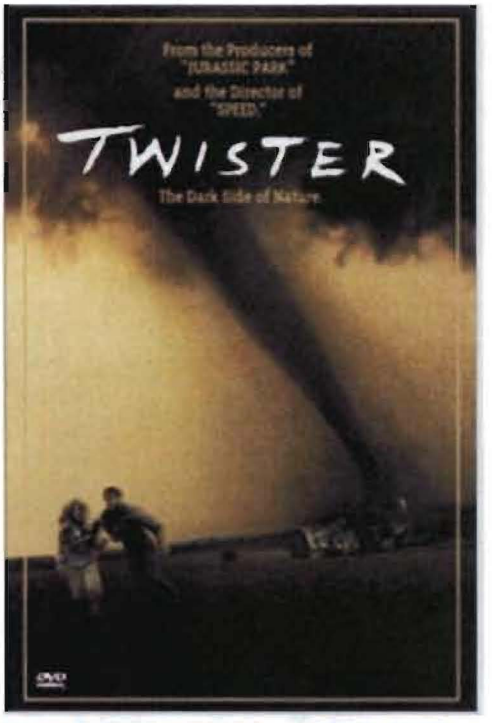

Figure 9: *Twister* movie poster (IMDb, 2010)

Instrumentation: Tornado prediction, detection, and measurement

Measuring instruments have been a key to understanding weather cycles and phenomena. In the movie, the team uses a variety of instruments that provide them with access to things such as wind speed, direction, precipitation, and so on. The first modern instrument presented in the movie is the GOES 8 weather satellite. The GOES 8 is a real weather satellite that was in operation from 1994 to 2003. It was the first in a new series of satellites that had three-axis stabilization and had an imager and sounder that allowed for simultaneous readings and functions of each (Chesters, 2015). In the movie the team is trying to deploy an instrument they have named Dorothy that contains small ball-like measuring instruments that once-released will transmit information such as winder speed, wind direction,

temperature, and other measurements back to the team on the ground. These readings are meant to aid in the prediction of tornadoes. Joe hopes that with more information of the inside of the tornados and how they change will help get warning time from three minutes to fifteen minutes. By the end of the movie, they are able to deploy one of these instruments but they needed to modify the instrument packs with soda cans so the packs would have more lifting ability. In reality, there was an instrument created by the National Severe Storm Laboratory (NSSL) named TOTO (TOtable Tornado Observatory, figure 10) that was designed to perform functions similar to those in Twister. The main difference between the two is that TOTO was not designed to release hundreds of little balls to gather information. Instead, TOTO was equipped with instruments to take measurements for temperature, dew points, pressure, wind speed and direction, with its own recording device located in the base of the instrument.

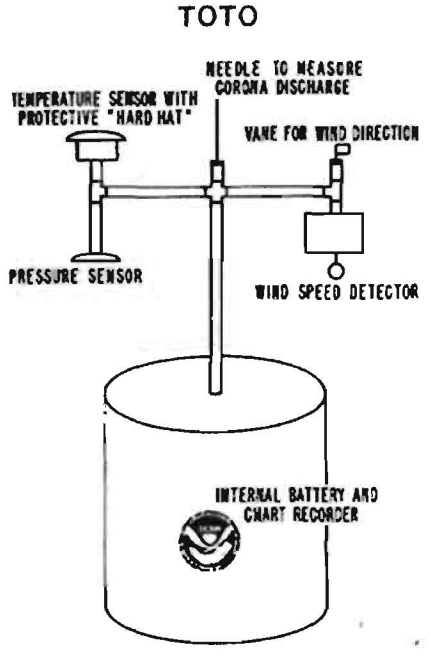

Figure 10: TOTO design (Bedard & Ramzy, 1983)

The deployment of TOTO was similar to that of Dorothy in Twister, except perhaps more dangerous. In the movie, the team would lower Dorothy to the ground from the back of a pickup truck in the line of the tornado. The winds would suck off the lid and the little balls for measuring would fly into the air. Dorothy probably would have worked with just being close enough to the tornado to have the lid ripped off because from there the measurement balls would be sucked out of the drum and most-likely then would be taken by the winds towards the tornado. The race to move Dorothy into the path of an oncoming tornado creates a much more exciting cinematic climax than observing a stationary instrument in the distance and is one example of writing triumphing over reality. With TOTO, there were

no flying instruments to take measurements which meant that in order for internal tornado measurements to be taken, the instrument must be deployed in the direct path of the tornado. This left quite a few issues to deal with, the first being that tornado direction can shift in seconds. Safety issues were a big concern as well. TOTO was driven to the location of placement in the back of a pickup and had to be set on a flat enough surface in the path of the tornado. Once the location of placement was decided, TOTO was rolled down a set of ramps with the help of a few casters mounted to the bottom of the device. From there, the personnel would flee from the dangerous location (Bedard & Ramzy, 1983).

Terminology

Twister uses a variety of terms that are associated with stability indices. "Cap" is a term used in a few scenes of the movie and stands for capping inversion which is "a statically stable layer at the top of the atmospheric boundary layer." (American Meteorological Society, 2012). Cap is a factor in what makes or breaks a severe weather outbreak. If the cap is too strong and does not break then storms are unlikely to develop. If the cap breaks too early in the day, you might see a squall line develop but not the isolated severe storm cells that are more likely to produce tornadic activity. For ideal super cells, cap needs to break between about 2 and 4 pm which is the time period at which daytime heating will be at its highest point. At the beginning of Twister, the 7 am forecast is being read aloud and at one point one of the forecasters says "the cap is already starting to break...cells keep building." Lifted index is another term that is thrown out at the beginning of the movie. It is used to determine the stability of the atmosphere. According to the National Weather Service, a lifted index of -4 or less is an indication that severe thunderstorms are possible (FFC Webmast, 2009). A dry-line is a boundary separating moist air from dry air. In the Great Plains region, it separates the moist air coming from the Gulf of Mexico and the dry air from the desert states in the southwest. Severe storms and possibly tornadic storms can develop along the dry-line or just east of the dry-line where the moist air is located and then move eastward across the states (National Weather Service, 2009).

Throughout the movie, the twisters are given strength designations such as F-2 or F-5. The designations they are using come from the Fujita scale that was developed in 1971 by Dr. T. Theodore Fujita. There are six categories that are used operationally in the Fujita scale that rank a tornado based on the intensity and area starting with an F-0 being the weakest and an F-5 being the strongest. "The Fujita Scale is a well-known scale that uses damage caused by a tornado and relates the damage to the fastest 1/4-mile wind at the height of a damaged structure." (Storm Prediction Center, 2014). In the movie *Twister*, you will hear some of these designations being given to the twisters as the team are chasing. The issue associated with these designations in the movie is that the team members are being told or guessing the F rating of a tornado before or while the tornado is on the ground and thus before the damage can be assessed. There are some cases where the EF rating of a tornado can be made with an educated guess by someone who knows the rating system and thus give a general idea of what the strength of a tornado may be while it's on the ground. Due to some complications observed with the Fujita scale such as the cases where tornados don't destroy infrastructure or the lack of considering different construction stability, the Fujita scale was revised in 2007 by a team of meteorologists and wind engineers and uses 28 indicators and eight levels of damage to judge the strength of a tornado from three second wind gusts (Storm Prediction Center, 2015).

Downdrafts are a wind occurrence that can also cause significant damage. In the scene at the drive-in where the tornado rips apart the screen and throws cars in the air, one of the team members says that the tornado only side-swiped them and what they were experiencing were the downdrafts and microbursts. A downdraft occurs when rain-cooled air sinks inside a thunderstorm and carries some of the strong winds aloft downwards with it. Once the downdraft reaches the ground, it must spread out laterally across the land. Intense downdrafts from thunderstorms can lead to some amount of wind damage. A downdraft is considered a microburst if the winds extend four kilometers or less and last for several minutes (Grenci & Nese, 2010).

While some of the lingo used in Twister is credible and used professionally, some terms are not used appropriately for the given context. At the beginning, one of the chasers is explaining what he calls the "suck-zone" as the point at which a twister sucks everything in its path up. What he is referring to is the rotation causing the pressure in the tornadic thunderstorm to fall which leads to an acceleration of the inflowing ground wind as it rises into the updraft (Konop, 1998). Another term the chasers use that is not exactly true scientific wording is calling a pair of tornadoes that they are chasing across a bridge a pair of "sister tornadoes."

What they are actually referring to is something called multiple vortices. This concept occurs when several smaller rotating twisters center themselves on one large rotation. In Twister, we see the two tornadoes merge into one. This is actually possible, just extremely rare. When it does happen, it is usually the larger and stronger tornado that swallows up the smaller "sister twister" (Edwards, 2015).

One final term that is used in Twister that is not necessarily used in real life is when Jo and Bill are chasing a large tornado that dissipates for a few minutes; one of the team members calls the dissipation period the "cone of silence." In the movie, the cone of silence is intended to describe the time period between a lulls in ground time for a multiple touch-down tornadic storm. The team member says that the tornado is back-building and will touch back down stronger than it was before. In a sense, this has some truth to it in that a tornado might lose its strength and dissipate for a few moments and then re-touchdown with what would seem like a stronger formation and wind power. It doesn't necessarily pick up a random amount of energy from out of nowhere to make it stronger; it merely refocuses the strength that it had before back into rotation. Thus the "cone of silence" isn't

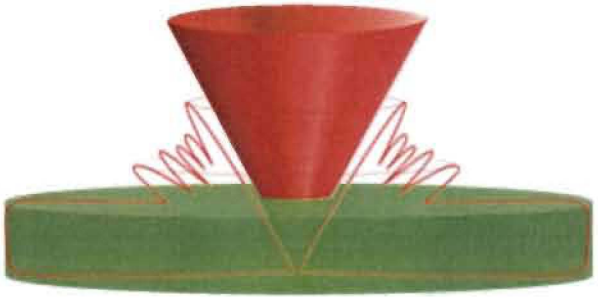

Figure 11: Cone of Silence

some terrifying event that occurs in tornadic thunderstorms. The 'cone of silence' actually refers to radar technology. The antenna rotation doesn't include the space directly above the antenna location, thus a conical area is left without data on radar (figure 11) (Wolff, 1997).

Formation of a Twister

Throughout Twister, the team brings up various weather conditions that are occurring in the area that causes them to drop everything and start their chase. Some of these include green skies, mammatus clouds, wind direction, dew points, shifting of the updraft and veering of upper level wind, and so on. One of the fundamentals has already been mentioned as to when severe activity could be seen; that of the breaking cap. It is important to know what else leads to severe and tornadic activity.

To begin, a supercell is a separate thunderstorm cell that has a rotating updraft. Supercells are the type of thunderstorms that produce the strongest tornadoes and the largest hail (Grenci & Nese, 2010). To form a supercell, an air parcel must rise until it reaches what is known as its lifting condensation level and form a cumulus cloud. This rising air is called an updraft and it rotates aloft in a supercell. Supercells develop where there is a strong vertical wind shear that interacts with the rotating updraft to prevent dissipation that would normally occur with a single cell thunderstorm from the downdraft. Vertical wind shear occurs when there are slow moving winds in the lower levels of the atmosphere and faster moving winds in the upper levels of the atmosphere. This creates a horizontal rotation in the updraft. This updraft can then turn vertical to create a tornado that touches down (figure 12).

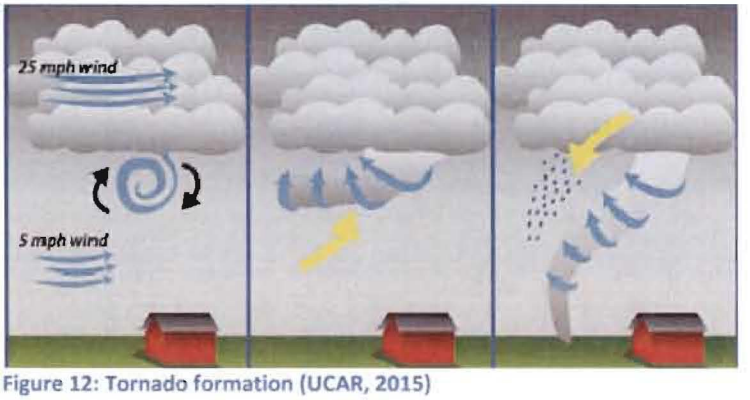

Figure 12: Tornado formation (UCAR, 2015)

Within the supercell organization, there is an area of low pressure called a mesocyclone. The mesocyclone is the area within a supercell that a tornado would spawn from. It is created when the low level warm, humid air that is being rotated gets tilted upward and then converts to a counterclockwise vertical rotation. Most of the time thunderstorms move from the southwest to the northeast while tornadoes themselves do not follow an actual path and can shift their direction at any moment. When this direction of movement occurs with a thunderstorm, the hook would be seen on the southwestern part of the cell which means that is also the area where the tornado would form. In order for the storm to actually produce a tornado, the rotating updraft must get tighter in diameter and longer in vertical height which increases the speed of the rotation. If the column of circulating air descends with the rear downdraft, and then some of that sinking air pulled back into the humid updraft, the angular momentum will continue to increase and if it can spin fast enough, a tornado could form. Another way that tornadoes can develop is from converging air near the ground that works its way up. These kinds of tornadoes are known as landspouts.

While the team is chasing one of the tornados, Jo notes the color of the sky is turning green. The green sky is not a proven fact associated with thunderstorms but it is something that a lot of people believe. The sky coloring can be generated from a variety of sources; the angle of the sun and the way it is hitting the clouds or even the precipitation that is falling in the storm can both lead to a unique coloring of the sky.

The dew point reaching 70 degrees Fahrenheit is a rare feat but not impossible. A high dew point means that there is a lot of moisture in the low levels of the atmosphere. Warm moist air in the low levels combined with dry air in the mid-levels of the atmosphere is a recipe for severe, explosive thunderstorms.

In a few scenes throughout the movie, the storm chasers say that the tornado path is stable or that they believe the tornado is about to shift its path in a specific direction. There is no way of determining when and which direction a tornado is about to shift. While storm tracks tend to stay on a pattern from southwest to northeast, tornados can shift their direction with extreme speed putting chasers in danger if they were under the impression that it were on a stable path.

When the team is chasing the sister twisters, they are chatting heavily on the radar about what is going on in the surrounding atmosphere. One of them says that the main updraft is shifting and the upper level winds are veering which is a true indicator of the formation of a twister. Veering means that the wind is shifting direction with height usually in a clockwise manner. At one point, the scene cuts to the prediction center where they say they can see a pronounced hook in the storm on the radar. This would be another real indicator of a tornado possibly forming. One of the team members tells Jo and Bill that the storm motion is 225 degrees straight from the southwest which supports the fact that most thunderstorms have a southwest to northeast movement. Another team member says that the atmosphere is unstable; a conditionally unstable atmosphere occurs in the presence of a cold front or dry-line and leads to the rising of the air pocket to produce the storm and keep it from dissipating.

Impacts of Twisters

During the course of the movie, Bill and Jo are able to survive some pretty intense events that would have led to death and dismemberment in the real world. In one scene they take cover under a wooden bridge while the tornado sucks up their truck, a tractor on top of the bridge, and even some panels from the top of the bridge. They survive by wrapping their arms around the vertical wooden posts that are supporting the bridge. Another crazy event happens when they are chasing the sister tornados and drive out onto a dock/bridge on the lake. Flying around them are cows and other debris. The pair, along with Bill's future wife, is in their average Dodge pickup truck when one of the twisters

moves directly over them and spins them around a little bit before dissipating. Once again, not exactly a realistic situation especially with the amount of debris that was flying around them. The debris alone probably would have shattered some windows and the wind would have at least knocked the truck off into the water, if not pick it up and throw it.

The final tornado of the movie has been classified as an F-5 when they start to chase it. According to the original Fujita scale, an F-5 tornado would have wind speeds anywhere from 261 mph to 318 mph and would have the strength to level strong framed houses and send automobiles flying up to 300 feet (Storm Prediction Center, 2015). A variety of other incredible phenomena have occurred with that strength of tornadoes as well.

Bill and Jo set off to deploy Dorothy and finally make their dream come true. They are following the tornado on a side road when they see the tornado pick up a semi-truck and trailer and send it flying high and far through the air. The tornado then changes track and they have to flee while debris hinders their path such as the large framed house that rolls onto the road and they ram through it with a few explosions and no broken windows. They decide that the best option for their safety and research is to drive through a cornfield, set the cruise control, and jump out of the truck. Once the truck has made it into the tornado and they have had a moment to celebrate, the tornado changes its path and begins following the couple as they make their way towards safety. The fastest recorded ground speed of a tornado is 73 mph while the slowest is 10 mph (National Weather Service, 2009). The average pace of elite runners, depending on the length of the race, is anywhere from 11 mph to just under 25 mph (Universty of Miami Online, 2015). Ergo, if Jo and Bill are in pretty good shape and the tornado that is chasing them is one of the slowest on record, they may be able to outrun the F-5 vortex that is leveling everything in its path.

The twister sucks up the barn around them and Bill and Jo decide to tie themselves with leather belts to a plumbing pipe that extends into the ground "at least a hundred feet." The scene shows them being pulled upside down from the winds but they are able to open their eyes and watch the debris fly around them but not come close enough to scratch them. If the tornado truly were an F-5 and it passed directly over them while they were strapped to that pipe, their limbs would have been ripped off, if not at least pulled pretty hard to leave them disfigured and heavily injured.

Conclusion

While *Twister* identifies several meteorological aspects that are relevant and truthful, it also stretches the truth about tornadoes and safety methods while chasing. The biggest concern with an audience watching this movie would be that they would want to go out and try chasing storms using the techniques observed in this film. While the characters manage to escape harm, in real-life and especially for amateur chasers, some of the methods in the movie could lead to injuries or loss of life. It is important to understand the basics in the formation of tornadoes and how they can impact the structures surrounding them to prevent endangering oneself or the people around you.

Extraordinary Weather Events - *500 mph Storm*

Figure 13: *500 mph Storm* movie poster (IMDb, 2013)

500 mph Storm (2013) is a straight to television sci-fi film that stars Casper Van Dien and Michael Beach as the main characters. Nathan is a science teacher trying to get his family to safety and Simon is a leader at the Apollo Station – a station that will change the way the world consumes energy. The station has a reactor that shoots a beam into the atmosphere and initiates a cataclysmic set of events that include a hurricane that reaches land in mere minutes and severe weather spanning the south western United States. Meanwhile, the core of the station is going into a critical meltdown mode. The storm and the reactor are feeding off of each other's energy and if one breaks down then the other cannot be stopped. In order to stop the storms from forming a monster sized hurricane, Nathan must reconnect his cell phone signal and contact Simon with the coordinates of the eye of the storm. If the particle beam can hit the center of the eye, the beam and the hurricane will cancel each other's energy and the world will be saved. While the acting and the special effects are subpar, the movie is entertaining and offers some interesting, yet scientifically questionable, action sequences. The main theme of climate modification and its consequences in *500 mph Storm* are analyzed with a focus on the likelihood of the rapid cataclysmic events that ensue.

Instrumentation

The reason why a destructive and bizarre storm forms is due to Apollo Station, a hypothetical green energy reactor designed to help eliminate the human carbon footprint. The reactor is a byproduct

of climate engineering, the technological manipulation of climate with the intention of forestalling or reversing negative climate change (Climate Engineering Conference, 2015). The movie does not go into much detail about how the reactor actually works, only that it is powerful enough to affect global climate and backfire in a cataclysmic way.

Other than the main reactor at the station, instrumentation is not largely discussed, shown, or used to take measurements on the hurricanes and tornados in the movie. However, there are some real-life instrumentation that can aid in understanding the formation and trajectory of a hurricane or tornado. These include satellites, ocean buoys, and aircraft.

Satellites can be used to track a hurricane. The radar can identify patches of showers or thunderstorms over the oceans that might lead to tropical storm development. If the cyclone develops, radar can monitor the height of cloud tops and where the heaviest rainfall would be occurring. A visible satellite image can identify cloud heights and types and can also monitor how far out the clouds extend from the center of the cyclone. Infrared imagery and water vapor imagery are also helpful when tracking a hurricane. The water vapor can show how much moisture is in the upper atmosphere and the infrared imagery can identify the clouds based on their temperature relative to the surface. Satellites are not mentioned in the movie as a way of tracking the storm that forms and makes landfall.

Ocean buoys are equipped to measure air and water temperature, atmospheric pressure, humidity, wind speeds, and other variables. Ocean temperature plays a large role in the development of a hurricane along with the air temperature and humidity. Hurricanes gain their strength not only from warm surface water but also from warm water several meters below the surface. Greater detail about hurricane formation is discussed later in this chapter. Wind speeds are vital to identifying the strength of a hurricane and knowing the strength can help warn people living near the area of landfall of what is coming and what to expect. Evacuation may be necessary to prevent a massive loss of lives. In the

movie, it is mentioned early on that the storm has already claimed 2300 lives; Hurricane Katrina in 2005 claimed the lives of 1,833 people (CNN Library, 2014). The storm also made landfall in mere minutes which prevented a proper warning from being issued.

Aircraft plays a large role in the understanding of hurricanes and tracking their wind speeds. NASA, NOAA, and the US Air Force all have aircraft that they use to gather measurements about developing storms and hurricanes. The Air Force calls their fleet of airmen and aircraft the Hurricane Hunters. The planes used by the Hurricane Hunters do not have any structural reinforcements; the planes do have extra fuel tanks added to allow for a longer flight time. Some of the major equipment uses on the planes are atmospheric profiling systems and a GPS dropsonde that records wind speed and direction, temperature, humidity, current pressure, and GPS position. The data collected can be used to produce soundings, maps, and profiles that help to forecast the path of the hurricane and the possible strengthening or weakening of a hurricane (Hurricane Hunters Association).

Figure 14: Hurricane hunting plane from the US Air Force (Hurricane Hunters Association)

Terminology

The movie characters incorrectly denote the tropical storm/hurricane with F-scale ratings. An F rating is a grade given to a tornado based on the amount of destruction from which wind speeds are estimated. In contrast, hurricanes are actually measured using the Saffir-Simpson scale based on maximum wind speeds, not damage. Developed by Herbert Saffir and Bob Simpson in 1969, the Saffir-Simpson scale ranks hurricanes into one of five different categories. Category one is the lowest rank that a hurricane can receive and the wind speeds range from 74-95 mph while category five is associated

with hurricane wind speeds of 155 mph or greater (Atlantic Oceanography and Meteorological Laboratory, 2006). The hurricane that develops in *500 mph Storm* would be a Category 5 because its wind speeds far exceed the boundary for any other category.

At the beginning of the movie, when Simon is informed that pressure readings are off the charts, he claims that the reactor tore a hole in the ozone that is 1000 square feet in area and growing. There is a common misconception that there is a true hole in the ozone meaning that a portion of the ozone layer of the atmosphere is completely gone. The ozone "hole" is actually just a weakened portion of the ozone layer; its thickness is much less than that of the remaining ozone layer. Figure 15 shows the annual thickness of the ozone layer in Dobson units from 1995-2007. Dobson units measure the density of ozone in a vertical column: 100 Dobson units correspond to 1 mm thickness of ozone (Douglass, Newman, & Solomon, 2014). Figure 15 shows that the ozone hole is actually just an area where there has been significant depletion in the thickness of the ozone layer. Over Antarctica, the ozone layer has been sitting around 100 Dobson Units, or 1 mm, for quite a few years now. Other areas of the earth are indicated as having 300 DUs thick ozone layer and even 500 DUs thick ozone layer. Weakening the ozone hole has taken several decades to achieve the most severe reduction in thickness. Based off of this data, it would take a very powerful source to cause an immediate weakening that happens in the film.

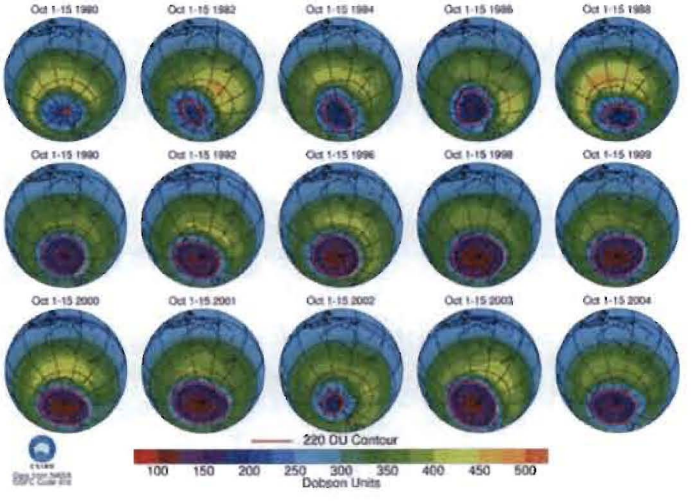

Figure 15: Ozone layer thickness in Dobson Units (DU) from 1995-2007 (Australian Government, 2006)

Weather Phenomenon

500 mph Storm showcases a variety of weather phenomena such as hurricanes, tornadoes, and wildfires with varying degrees of accuracy. For Example, two scenes from the movie show hot air balloons spinning around a tornado. The hot air balloons are still fully intact and have not been torn apart at all. This would not happen in a real life tornado. While cars and buildings can be tossed by strong tornadoes and remain whole, a hot air balloon is made of fabric and a basket. The fabric would have torn apart from the wind pulling it along with the other debris that is present in a funnel. In another film sequence, a tornado is chasing the main characters at a very close distance, maybe twenty feet, and for an extended time period (several hours). Tornados are not attracted to specific objects and people and the tornado movements shown are highly unlikely. Also, the proximity of the tornado to the car would more than likely have made the vehicle airborne with serious or fatal injuries befalling the characters.

The main reason why the hurricane in the movie causes a large amount of problems is the short amount of time that it takes for the hurricane to gather strength and organization and then make landfall. The hurricane is at a high category within minutes of the reactor being turned on. In reality, the fastest amount of time it takes for a hurricane to reach an organized structure and intense strength is on the magnitude of hours.

A tropical cyclone's life begins as a patch of thunderstorms or showers that lack organization. These patches are known as tropical disturbances. If the correct recipe exists with the water and atmosphere, the disorganized showers and storms can develop into a tropical storm. There are certain conditions necessary for the formation of a tropical storm and eventual hurricane. The process takes hours to days to create a hurricane, especially a strong one.

Hurricanes are fueled by warm water. The water needs to be roughly 80 degrees Fahrenheit or higher at the surface. The warm water aids in destabilizing the air above the surface in the troposphere which then leads to deep convection. The high ocean surface temperatures initiate high evaporation rates and high dew points which help to strengthen the cyclone. The warmth must extend beneath the water's surface relatively deep to maintain the high sea surface temperatures. This is because the cyclone is rapidly evaporating and incorporating the surface water while mixing the upper surface water layers with colder waters below to create a localized upwelling affect. If the warm water temperature does not extend very far beneath the surface, the mixed water layer could limit further convection (and latent heat energy) and weaken the tropical cyclone.

Along with warm water temperatures at the surface and deep below the surface, a cyclone also needs instability in the troposphere to help the rising parcels of air that have risen because of the high dew points causing net condensation to occur early in the ascension of the air parcel. These air parcels can continue to rise because the parcels remain warmer than the surrounding environment in the troposphere due to the release of latent heat. When the parcels reach the top of the thunderstorms, some of them move away from the center of the cyclone which promotes upper-level divergence while other parcels sink into the central column of the cyclone and heat up from compression of the air. This means that the center of the cyclone will have the highest temperature and a low pressure at the surface (Grenci & Nese, 2010).

The main destructive event of the movie is the possibility of hurricanes developing over North America and combining to form an extraordinarily large central vortex with winds exceeding 500 mph or so-called "Hypercane". Not just the work of Hollywood fiction, his hypercane theory was proposed by Kerry Emanuel and others as "... extraordinarily intense hurricanes whose energy production is so large that it cannot be balanced by surface dissipation, resulting in storms so intense that internal dissipation

becomes important" (Emanuel et al., 1995). What this means is that a hypercane could actually be possible if an energy source strong enough to feed the system were accessible. In order for the hypercane to dissipate, internal balance would have to be achieved; it would have to choke itself off possibly by moving over a land mass where there were dry air that will weaken the system.

In *500 mph Storm*, Nathan continually says that they need to get to higher ground to get above the low pressure system. He says, "There is no hurricane or tornado in all of nature that could reach high enough to touch us," as they are making their way to the top of the Guadalupe Mountains in Texas. Tornadoes have been recorded in the mountains in reality. In 2004, a tornado touched down at 12,000 feet in California at the Sequoia National Forest and holds the record as the highest altitude for a touchdown (NBC News, 2012). Colorado also experiences tornadoes in its mountainous areas although they are rare. The reason for the rarity of tornadoes in the mountains is because at high elevations, the air is already cooler and thus more stable than the air at sea level. Unstable air is necessary for the formation of thunderstorms.

As for hurricanes, they can pass over some decently tall mountains but at the cost of losing strength. In 2009, Typhoon Morakot passed over Taiwan before making landfall in China. When it hit Taiwan it was a category two on the Saffir-Simpson scale with 100 mph winds (Hurricanes: Science and Society, 2015). After passing over the mountains that have a peak named Yushan whose peak is just less than 13,000 feet, the typhoon became a tropical storm with wind speeds between 55-72 mph. Because unstable air and high temperatures near the ocean surface are ideal for building and sustaining a hurricane, as soon as one passes over a mountain range and meets the cooler, drier air as well as experience more friction from the topography causing a drag in the wind speed, the hurricane would begin to weaken. Ergo, Nathan is incorrect when he tells his son they will be perfectly safe on the mountain top because they can outrun the bad weather.

Conclusion

500 mph Storm is a movie fit for entertainment purposes only. The film spun some of the factual information about hurricanes and tornados into an overly-exaggerated and untrustworthy source. One thing that the film highlighted that some people may not have heard of before is the hypercane theory and that it could possibly happen given the right circumstances. However, every other aspect of the film is overreacted and embellished. The characters do make it to safety and are able to shut down the device that is feeding the hypercane by putting themselves in continuous danger which makes for a thrilling film to watch.

Historical Weather Occurrence – *The Perfect Storm*

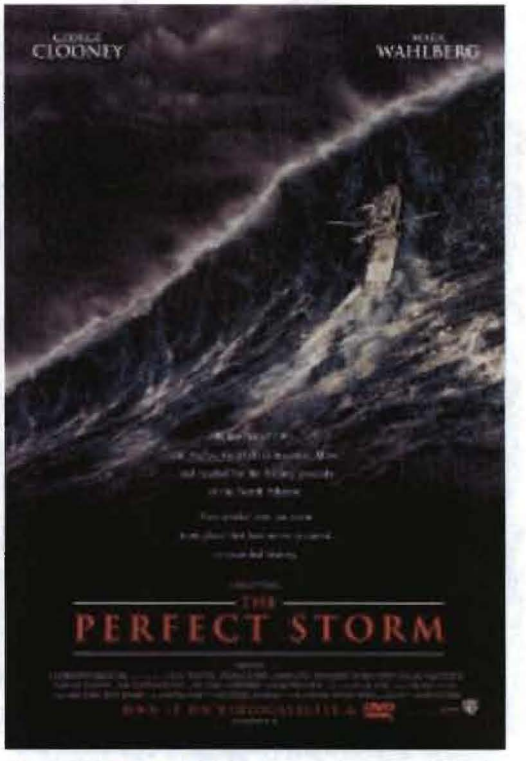

Figure 16: The Perfect Storm movie poster (IMDb, 2010)

The Perfect Storm (2000) is a movie that is set in the year 1991 in Massachusetts and the Atlantic Ocean. George Clooney and Mark Wahlburg star in the film as two of the sword fishermen on the boat the Andrea Gail. This film is based off of a true event both in terms of weather and the men who were lost at sea during the event. Captain Billy Tyne (Clooney) has been having a difficult time finding the swordfish out at sea and thus has not been bringing in high yields. His men are not making the promised amount of money and are starting to mistrust him. Nearing the end of the fall fishing season, Tyne decides to pack up and head out to sea one more time. They pass their usual grounds known as the Grand Banks where they do not catch much and make their way towards a more remote place known as the Flemish Cap. Meanwhile, Hurricane Grace is strengthening near Bermuda, a Halloween snowstorm is impacting the Northeast and there is a disturbance off the coast of New England. The three storm systems combine to form the "storm of the century" making travel across the North Atlantic extremely dangerous. Unfortunately for Billy and his crew, their path leads directly into the heart of the combining monstrous system and sets-up this true-based story about the heartbreaking loss of six fishermen brave enough to battle the storms in an attempt to make it home to their loved ones.

This film provides insight into an actual historical weather phenomenon that occurred in late October through the early days of November during the year 1991. While some portions of the facts from this event are stretched to make the story more interesting, a large portion of the details from the

movie can be proven truthful. Not only does this film highlight an extraordinary occurrence in weather history, it also brings into the light some serious concerns of safety while out at sea and the importance of paying close attention not just to the daily forecast of weather but also the possibilities of future weather.

The Real Life Event

There were several interacting systems that played a role in the weather events known as the Perfect Storm. Hurricane Grace was making its way north along the Atlantic seaboard which brought significant moisture to the low-pressure system that established itself along a cold front that was making its way across New England. This system had a center just southeast of the Canadian provinces and coastal Maine.. Behind the cold front was a large high pressure system that intensified over the northeastern United States to an almost record maximum of 1046 mb (Hoke, 2014). The low that was situated off the Nova Scotia/Maine coast deepened and became the dominant force in the western Atlantic. Hurricane Grace continued in a northwesterly path along the east coast until its interaction with the mid-latitude low pressure center caused a shift in its path to an eastward direction. As the cold front collided with Grace it destroyed the circulation of the Hurricane just off the coast of Bermuda. The moisture leftover from Grace was quickly absorbed into the rotation of the low-pressure system but did not enter the rotation center. The high pressure that was just behind the cold front kept the system from moving northward. The low pressure system moved southeastward and then southwestward deepening the

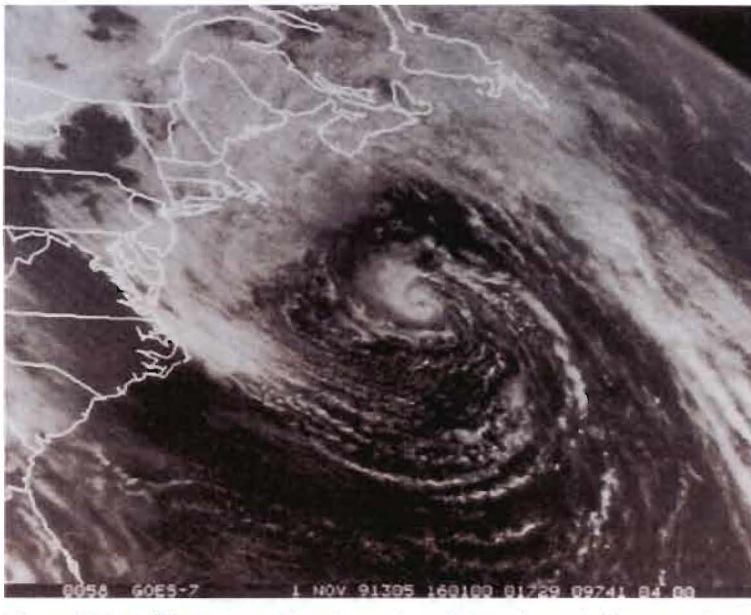

Figure 17: Satellite image of the formation of the subtropical storm prior to becoming the unnamed hurricane (Mcgahee, 2008)

whole time. Then, it retrograded southwestward on October 31st and began moving southward on November 1st. This brought the cyclone over a portion of the Gulf Stream where sea surface temperatures of 80 degrees Fahrenheit were reported. The high temperatures of the ocean promoted convection within the center of the storm system and soon tropical storm characteristics were observed within the structure. This tropical storm even took on hurricane characteristics and is still known as the Unnamed Hurricane (Mcgahee, 2008).

Terminology

A cyclone is an area of low-pressure around which winds will either flow clockwise if it is located in the southern hemisphere or counterclockwise if it is located in the northern hemisphere (Grenci & Nese, 2010). There were several cyclones occurring and combining their forces as the Perfect Storm event ran its course. Eventually the low-pressure took on extra-tropical cyclone characteristics which occur when a low-pressure system that has noticeable circulation and forms over warm ocean water. The tropical storm that had once been Hurricane Grace dissipated and merely fed some precipitation into the tail-end of the unnamed hurricane that formed off the coast of New England.

A cold front is a boundary of denser air is moving forward and through less dense air. The dense air is usually cold, hence the name cold front, and/or drier than the air it is advancing upon which is generally warmer and/or moister (Grenci & Nese, 2010). In the movie, and the real-life event, the cold front collides with the advancing Hurricane Grace and eventually destroys Graces central circulation causing a decrease in the stability of the low-pressure that was off the New England coast along with increasing the convection taking place over the Gulf Stream and thereby increasing the strength of the cyclone. If the cold front had not been there to upset Grace, the colliding systems may not have led to the strong extra-tropical cyclone turning into a hurricane structure.

Gale force winds are mentioned in the movie with the weather report faxes that the ship was receiving as the storm built up. Winds are considered gale when they are in the range of 34-40 knots and the waves on the water reach a height of 18-25 feet. The tops of the crests break into a spindrift and the foam might start blowing off the tops in streaks. When on land, gale winds will break twigs off of trees and hamper movement of an individual, a car, or other form of transportation. Hurricane force winds are stronger, reaching speeds of 64 knots or greater and could cause waves to reach 45 or more feet with visibility greatly reduced by the spraying ocean foam (Storm Prediction Center, 2015). A tropical storm might reach speeds of 35-74 knots which falls into the range of the gale force winds. It is defined as a mass assembly of tropical clouds and thunderstorms that have an organized structure and cyclonic circulation (Grenci & Nese, 2010).

Myths and Truths in the Movie

In *The Perfect Storm*, Hurricane Grace is given a category 5 designation with winds sustained at 140 knots. Waves are cresting at 40-50 feet and there were gale force winds in the path that the fishermen decide to take to get home. In reality, Hurricane Grace had a large structure that generated ocean swells as far south as Florida reported to be about 10 feet high. Massachusetts experienced severe coastal flooding and there were also several reports from Jamaica to Newfoundland of damage from the storm surge (History.com Staff, 2009). The maximum intensity of Grace is estimated to be about 89-90 knot wind speed (Pasch & Avila, 1991). This places Grace in a category 2 hurricane designation (Atlantic Oceanography and Meteorological Laboratory, 2006); a lot less powerful than described in the movie. If Hurricane Grace had been a more powerful and more organized storm system, the cold front may not have broken the central circulation as easily as it did.

Wave heights in the movie appear colossal in comparison to the fishing boat that the men are traveling on. In the actual event, one Canadian buoy reported a peak wave height of about 98 feet. The

weather fax that made it to the Andrea Gail in the film was reporting waves of 40-50 feet. When the Andrea Gail was first making its way to the Grand Banks, a sea surface thermometer flashed on the screen for a moment reading at a temperature of about 64 degrees Fahrenheit. This is unusually warm for late October as far north as Massachusetts. The motion of the cyclone system after Grace had been destroyed and swallowed into the low-pressure system was southward which caused the cyclone to move over waters where sea surface temperatures were reported at about 78 degrees Fahrenheit. This area was a little bit southeast of the coast of Massachusetts (Pasch & Avila, 1991).

For the most part, *The Perfect Storm* stayed within the realm of reality as far as weather is concerned. The combining of the cyclones and hurricane was proven possible in 1991 and is what the movie is actually based on. The fate of the Andrea Gail and its crew members is based off of the real-life event that occurred. The waves and wind speeds being reported line up with what likely or did occur during the actual weather event.

Conclusion

The Perfect Storm was a film based off of a true historical weather phenomenon that took the lives of six fishermen of the 70-foot Andrea Gail swordfish boat. The film expanded on some aspects of the weather event to add excitement to the film but adhered to the actual facts in a more general sense. This film highlights some important aspects of safety at sea and how unpredictable the weather can actually be in certain circumstances.

Conclusion

Filmography will continue to take liberties with the information that is providing the base for the plot of a movie. Before believing all the information presented in a film, audience members should try to understand actual events and how they occur. This is especially important in situations where the audience may be afraid that something they see in a film could happen in real-life. In addition, audience members should take precautions and become well educated in the field of weather and safety before attempting to reenact scenes or have adventures like the characters do, for example storm chasing in *Twister*. Some writers and directors try to remain true to the factual information as was the case with the majority of *The Perfect Storm*. Others have no problems with embellishing information to make the story-line more thrilling like that of *500 mph Storm*. In reality, weather phenomena are interesting enough; no embellishment is necessary.

With this thesis I hope that I have inspired the audience to learn more about how the weather occurs and various aspects of the climate. A greater understanding of how earth's systems work can help eliminate fear and misleading information that may be presented in future films about weather or climate.

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